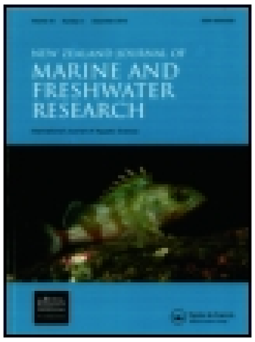

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Occurrence of the puerulus stage of the rock lobster, *Jasus edwardsii* at the New Plymouth Power Station, New Zealand

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Abstract More than 4000 specimens of the puerulus stage of the rock lobster, *Jasus edwardsii*, were collected in the sea water intake of the New Plymouth Power Station during 1977–84. Most specimens were caught between July and September. Sizes of pueruli were similar within years, but there were significant differences in size and number of pueruli between years. Puerulus occurrence was correlated with the late winter and spring increase in frequency of onshore winds, but the seasonality in settlement was probably not caused by this factor alone. Most pueruli at the power station were 9–13 months old, and occurred at any part of the lunar cycle. Oceanic flow patterns in the region suggested that most specimens originated from hatchings along the west coast of New Zealand, north of Hokitika. As the high numbers of pueruli at the power station were inconsistent with the zero catch of pueruli on adjacent collectors, and with the relatively low numbers of juveniles and adults nearby, the power station may attract pueruli.

Keywords *Jasus edwardsii*; larval recruitment; New Plymouth; New Zealand; Palinuridae; power station; puerulus; rock lobster; settlement

INTRODUCTION

The red rock lobster, *Jasus edwardsii* (Hutton) (Decapoda: Palinuridae), provides one of the most valuable fisheries in New Zealand. As for most other palinurids, little is known about larval recruitment in this species. A knowledge of seasonal, annual, and geographic variations in puerulus settlement will assist in understanding larval recruitment processes in *J. edwardsii* and will assist in the management of the fishery.

Palinurids have a complex life history. Eggs hatch and develop into leaf-like phyllosoma larvae which, after a series of moults, metamorphose to the puerulus stage. The puerulus resembles the juvenile in shape but is almost transparent. Phyllosoma larvae are poor swimmers (Phillips & Sastry 1980), most of their movements probably being restricted to diurnal vertical migrations. Pueruli, however, are capable of directional forward and backward swimming using their relatively large pleopods, as well as rapid backward swimming using abdomen flexing.

Late-staged (Stages 6–11) phyllosoma larvae of *J. edwardsii* have been caught most commonly beyond the edge of the continental shelf, and pueruli within it (Lesser 1978; Booth unpubl. data); metamorphosis probably occurs, therefore, near the shelf edge. At night, late-stage phyllosomas, as well as pueruli in waters away from the shoreline itself, were caught mainly in the upper 60 m. The phyllosomas dispersed to greater depths during the day (generally > 150 m), while pueruli moved onto or near the sea floor. Close to the shore, pueruli were often caught at night near the sea surface. These data are similar to those available for other palinurids elsewhere, e.g., *J. lalandii*—Pollock 1986, and *Panulirus cygnus*—Phillips 1981.

Most *J. edwardsii* pueruli settle in shallow (< 15 m), inshore areas (Booth unpubl. data). Settlement seasons and intensities vary according to area, although settlement occurs throughout the year at several sites (Booth 1979, unpubl. data; Booth & Tarring 1986). Within any particular area, the main settlement season is usually the same between nearby (within 20 km) sites. Settlement seasons at individual sites have generally been similar between years.

Late in the winter of 1977, large numbers of *J. edwardsii* pueruli were reported at the New Plymouth Power Station (39°05′S, 174°05′E) in Taranaki, on

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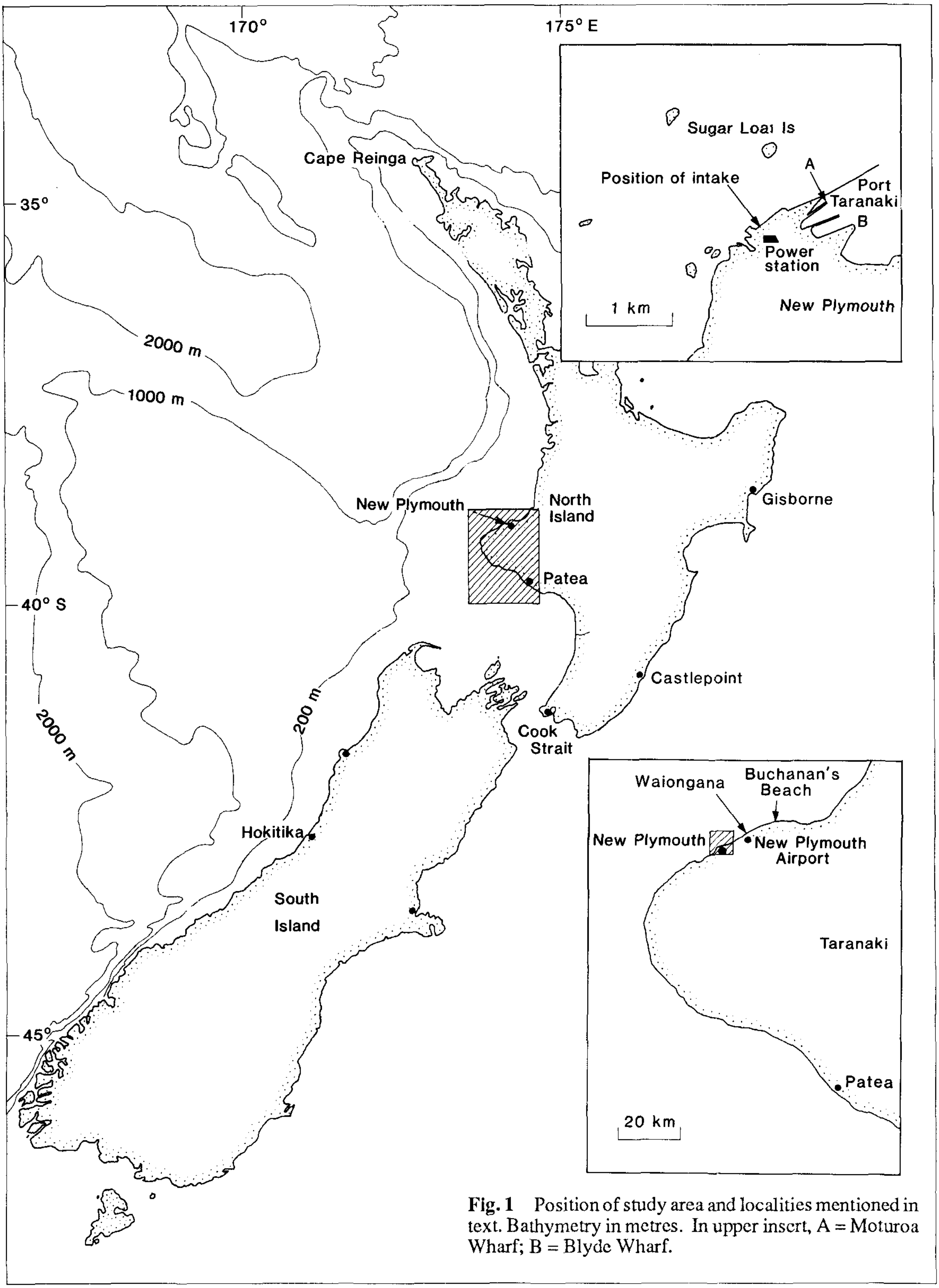

Fig. 1 Position of study area and localities mentioned in text. Bathymetry in metres. In upper insert, A = Moturoa Wharf; B = Blyde Wharf.

the west coast of the North Island (Fig. 1). The aim of this study was to investigate the seasonal occurrence and abundance, and behaviour, of pueruli at the power station, and to relate these to rock lobster larval recruitment in the Taranaki area. Such information may be useful in investigations of the larger *J. edwardsii* fisheries elsewhere in New Zealand.

METHODS

Power station collections

Numbers and size of *J. edwardsii* pueruli retained on the filter screens of the sea water intake of the cooling system of the New Plymouth Power Station were observed from October 1977. This paper deals with collections until December 1984, but observations continue. Sea water enters the thermal station through 10 pipes (1.4 m diameter) centred about 3 m below low water level in a north-west facing sea wall. The water feeds into a large silt trap in which sand settles out, and then flows through 5 filter screens (6 mm mesh) into the cooling system. Each of the 5 turbines requires $2.5 \times 10^2\ m^3\ min^{-1}$ sea water when on load (Ridgway 1973). The number of turbines on load varies seasonally according to electricity demand, but is similar between years for any particular season. Maximum generation is required during winter and spring, and a 1–2 week shutdown for maintenance usually occurs early each year. Except during the short shutdown, water flows generally remain within 70% of the maximum possible.

Material retained by the filter screens was composed of various marine organisms as well as general debris. This was removed by power station staff at least once a week (and often more than once a day), and sorted for pueruli, from October 1977 to December 1982. Occasionally, particularly during heavy swell conditions, the volume of material filtered was too great to sort it all; extrapolations of puerulus numbers were then made, based on the proportion of the material sorted. Since January 1983, collections have been less intensive, focusing mainly on the winter and spring periods and possibly resulting in lower annual totals of pueruli.

Collectors

The settlement of pueruli in areas adjacent to the power station was investigated over various periods during 1979–84 to relate to the power station catches. Three collectors (Booth & Tarring 1986) were suspended at different levels in the water column from each of the Moturoa and Blyde Wharves in Port Taranaki (Fig. 1) in June 1979 and checked approximately 3-monthly for pueruli until February 1981. Harbour Board divers had reported small juvenile rock lobsters around Blyde Wharf; Moturoa Wharf seemed to be a backwater in which marine debris (and perhaps plankton) accumulated. On 29 May 1983, 3 more collectors were set attached to concrete weights at low water depths of 4–10 m on the lee shores of some of the Sugar Loaf Islands, 1–2 km off the cooling water intake of the power station. These were checked on 10 July, 1 September, and 14 and 29 October 1983. Three collectors were similarly set at about 3 m low water depth at both Waiongana and Buchanan's Beach (13 and 23 km north-east of New Plymouth) in November 1983 and checked every 1–2 months until October 1984 (Taranaki Catchment Commission unpubl. data).

RESULTS

Numbers and seasonality of puerulus occurrence

The number of pueruli at the power station was relatively low during 1978 and 1979 (126 and 65, respectively), higher during 1980 and 1981 (437 and 385), and highest during 1982 (2513) (Fig. 2). The less intensive collections during 1983 and 1984 resulted in 422 and 60 pueruli, respectively. No specimens of the other major rock lobster species in New Zealand, *J. verreauxi*, were caught. No pueruli were caught on the collectors set in areas adjacent to the Power Station.

During 1977–82, pueruli were caught mainly during July–September, although they appeared in large numbers a little earlier (June) in 1982, and persisted a little later (November) in 1977. Seasonality was similar during 1983–84, with high numbers in 1983 from June to November. Few specimens were collected outside these months, but the results for summer and autumn may be slightly low because of short partial or complete station shutdowns during those seasons. The highest monthly catch was 1797, in July 1982.

Regular observations during 1977 began in October, but power station and local Ministry of Agriculture and Fisheries staff reported pueruli over a similar period that year as in subsequent years. Pueruli began appearing in very small numbers in April, several hundred were observed in early August, and numbers then fell during late August and

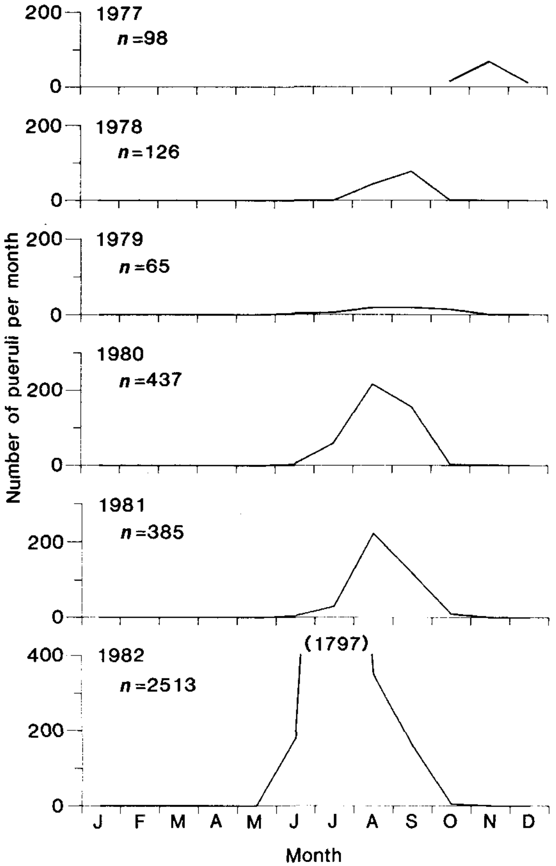

Fig. 2 Monthly occurrence of puerulus stage of *Jasus edwardsii* at New Plymouth Power Station, October 1977–December 1982. Large numbers of pueruli began appearing in August 1977 (see text).

September. There were far more pueruli during 1977 than in the previous 3 years.

There was correlation between the seasonal occurrence of pueruli and onshore winds from the west (Fig. 2 and 3). The monthly frequency of winds from all quarters was highly variable. Westerly winds (240–320°) showed the most marked seasonality: their frequency in all years was high during late winter, spring, and summer, but generally low during autumn and early winter. This is a feature not only of New Plymouth weather (New Zealand Meteorological Service 1982), but also of the weather of surrounding coasts (Thompson 1981; New Zealand Meteorological Service unpubl. data; Wratt & Homes 1984), and of areas up to at least 300 km offshore (Reid & Collen 1983). Most pueruli were caught at the time of the mid-year increase in frequency of westerly winds; these winds may assist in the shoreward transport of late-stage phyllosomas and pueruli.

From analysis of the 1982 winds at New Plymouth—not shown here—hourly readings (as opposed to night readings only) at New Plymouth are suitable to describe winds affecting the distribution of late-stage phyllosoma larvae and pueruli, even though these stages will be influenced most by wind-induced surface water movements when near the surface at night. The strength of the westerly winds, compared with the strength of winds from other directions, may also be a key factor in the seasonal occurrence of pueruli near New Plymouth. During winter and spring 1982, for example, strong winds (≥ 17 knots; 8.7 m s^{-1}) at New Plymouth were most frequent from the west (240–320°) (New Zealand Meteorological Service unpubl. data; Wratt & Homes 1984). This also applied to the longer period 1968–78 (New Zealand Meteorological Service 1982). Strong winds at New Plymouth presumably are reflected by strong winds in the area of the late-stage phyllosomas and pueruli offshore; Neale & Thompson (1978) found, 500 km further to the south-west on the west coast of New Zealand, that winds offshore were generally stronger than those inshore.

Puerulus numbers at the power station varied significantly with time, not only during the year, but also over the main settlement months. During the peak catching month for the entire study (July 1982), for example, pueruli occurred at 2 peaks (9–14 and 26–30 July), with no specimens immediately before, between, or immediately after these periods. Most of the larger catches of pueruli during the study were made during the new moon period (defined as 2 days before new moon to 7 days after), but large catches were also made during full moon (Table 1).

Stage of development and size of specimens

Almost all pueruli caught were transparent (except for the eyes and the tips of the antennae), lacked any external sign of the digestive gland, and hence were still pelagic or had only recently settled (Booth 1979: table 1). Only 7 juveniles (all first- and second-moult post-pueruli) were taken. Presumably these specimens were caught in the screens after having previously settled and moulted elsewhere within the cooling intake, and would have been about 6 weeks old from settlement (Booth & Tarring 1986).

The mean size of pueruli caught during 1978 and 1981–84 was 12.0–12.3 mm CL (carapace length),

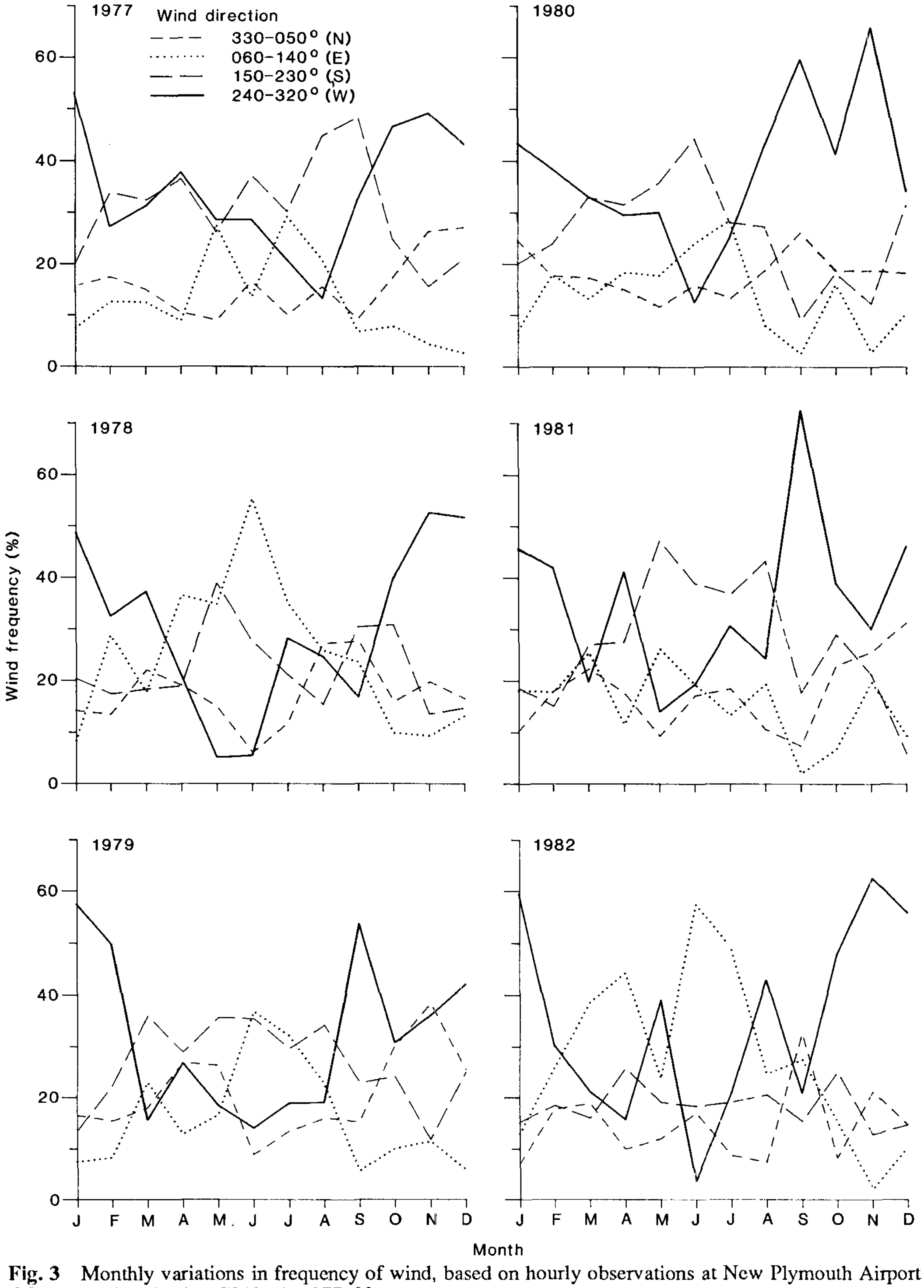

Fig. 3 Monthly variations in frequency of wind, based on hourly observations at New Plymouth Airport (Meteorological Station C94011), 1977–82.

whereas pueruli in 1977 and 1979–80 averaged 11.4–11.6 mm CL (Table 2). The size distributions of specimens were compared between years and months using the G-test (Sokal & Rohlf 1969). For the animals with the larger mean sizes, the 1981 size distribution was similar to that for 1982 ($P > 0.5$).

Table 1 Catches of *Jasus edwardsii* pueruli over new and full moon periods, New Plymouth Power Station, 1977–82. Timing of checks meant that in a few instances the puerulus numbers had to be estimated. New moon (NM) catches from 2 days before to 7 days after new moon; similar period for full moon (FM) catches.

		Puerulus catch		
Year	Month	NM	FM	% over NM
1977	Oct	8	9	47.1
	Nov	22	4	84.6
1978	Aug	0	38	0
	Sep	51	10	83.6
1979	Jun	3	2	60.0
	Jul	15	2	88.2
	Aug	10	0	100.0
	Sep	0	8	0
1980	Jun	0	14	0
	Jul	16	17	48.5
	Aug	75	173	30.2
	Sep	19	11	63.3
1981	Jul	16	0	100.0
	Jul/Aug	143	43	76.9
	Aug/Sep	114	5	95.8
	Sep/Oct	3	0	100.0
1982	Jun	51	43	54.3
	Jul	1252	93	93.1
	Aug	173	20	89.6
	Sep	103	30	77.4

The size distributions were different at $P = 0.05$ for all other combinations of years. Of the smaller animals, the sizes of those in 1980 were significantly different from those in 1978 and 1981–84, but they were similar to those available in 1977 ($P > 0.5$). Further size comparisons of the 1977 animals were not made because of the short collecting season; the sample size in 1979 was too small for comparisons to be made.

There was no significant difference in the sizes of pueruli between months within particular years as far as this was tested. The years 1980 and 1981 were investigated, when sample numbers were high and the size distributions of the pueruli were very different ($P \ll 0.05$). Pueruli caught in July, August, and September 1980 were similar in size ($P > 0.5$), as were those in August and September 1981 ($P > 0.1$). Monthly variations in size within other years also appeared to be small, but were not tested.

DISCUSSION

Puerulus numbers between years showed much more variation at the power station than in collector catches from most localities in New Zealand so far investigated. Pueruli also occurred at New Plymouth over a shorter period, and in greatest numbers during different months than at Castlepoint (December–July) or Gisborne (May–July) (Booth 1979; Booth & Tarring 1986).

Egg-hatching in *J. edwardsii* occurs mainly during spring. Assuming that pueruli caught in any one year were about to settle and were the result of hatchings in the previous year, then most of the specimens at the power station were 9–13 months of

Table 2 Size (mm carapace length) of *Jasus edwardsii* pueruli at New Plymouth Power Station, 1977–84. Specimens available from August and September 1977, before regular collections began, are included. Not all specimens from the other years were available for measurement.

Size (mm)	1977	1978	1979	1980	1981	1982	1983	1984
<10.0	1	1	0	6	1	0	0	0
10.0–10.4	3	5	1	28	5	28	3	0
10.5–10.9	19	8	4	56	6	93	13	3
11.0–11.4	28	11	8	132	30	147	37	15
11.5–11.9	25	29	14	104	56	341	71	8
12.0–12.4	14	31	6	57	122	643	96	17
12.5–12.9	4	24	6	18	89	540	84	14
≥13.0	0	12	0	0	42	215	63	3
Total	94	121	39	401	351	2007	367	60
Mean size	11.4	12.0	11.6	11.4	12.2	12.3	12.2	12.0

age. This is in the low part of the settlement age range of 6–23 months possible for *J. edwardsii* at Castlepoint (Lesser 1978; Booth 1979), but is similar to that for *J. edwardsii* at Gisborne (Booth & Tarring 1986) and for *Jasus* spp. elsewhere (*J. lalandii*—Lazarus 1967; *J. novaehollandiae*—pers. comm. R. K. Lewis, Department of Fisheries, G. P. O. Box 1625, Adelaide, South Australia).

Seasonality of puerulus occurrence

Wind is probably the major factor affecting seasonality of puerulus occurrence at New Plymouth. Egg hatching around New Zealand is highly seasonal and varies little with location, but is followed by a long and variable planktonic period (see above). Pueruli would then take only about 20–40 days to directly swim at night the 100 km width of the shelf near New Plymouth, assuming constant swimming speeds of 7–15 cm s^{-1} (Phillips & Sastry 1980), effective navigation, and currents being not too unfavourable. The high frequency of strong westerly winds during late winter and spring may assist in the shoreward transport of phyllosomas and pueruli. The precise ways in which these winds act on phyllosoma and puerulus distributions off New Plymouth are, however, unclear; surface currents flow up to 45° to the left of the wind direction, with the amount of deflection increasing with increasing depth. Onshore winds have also been implicated in shoreward phyllosoma and puerulus transport of *Jasus* spp. elsewhere (Winstanley 1977; Booth 1979).

Source of pueruli

The distribution of phyllosoma larvae is affected by ocean currents. Female *J. edwardsii* breed throughout New Zealand, but the general west-to-east oceanic flow past the country means hatchings along eastern shores of New Zealand are unlikely to contribute significantly to larval recruitment along the west coast. Available information on flow patterns suggests that most pueruli at New Plymouth result from hatchings along the west coast north of about Hokitika. One possible interpretation of larval drift in the area follows. The Tasman Current, a broad flow of Subtropical Water derived from the mixing of East Australian Current and West Wind Drift Waters, moves slowly northward along the west coast of New Zealand (Stanton 1973), with smaller-scale coastal currents further inshore. Coastal currents south of Hokitika flow generally southward. Larvae hatched north of Hokitika but south of Cook Strait are carried generally northward by the slow-moving Westland Current (Brodie 1960) as they move offshore. Larvae from hatchings along the west coast between Cape Reinga and Cook Strait are influenced by the Westland Current or the south-moving West Auckland Current (Garner 1961) as they move offshore. The variable direction of flow in this region, and the presence further offshore of the weak Tasman Current, mean that many larvae complete their development relatively close, latitudinally, to their point of hatching. This range in possible larval origins could help to account for the differences in puerulus size between years (see Lesser 1978).

Puerulus behaviour

Pueruli at New Plymouth occurred at any part of the lunar cycle, which is consistent with other observations on *J. edwardsii* elsewhere in New Zealand (Booth & Tarring 1986) and with the settlement of *J. novaehollandiae* (pers. comm. R. K. Lewis). Catches of several other palinurid species are, however, largely confined to the new moon period (Phillips & Sastry 1980).

The high numbers of pueruli at the power station are inconsistent with the zero catches on collectors set nearby and with the relatively low numbers of juveniles in the region. Divers report low abundance of small rock lobsters near New Plymouth compared with many other parts of the country, and of these small animals, most are just below the minimum legal size (MLS). The local commercial fishery is small (Sanders 1985) and fishermen along the Taranaki coast, particularly north of Patea, report a relatively low proportion of rock lobsters < MLS and a high proportion of large specimens in their pots. Sea water flowing through the intake pipes could entrain some pueruli, but large numbers of pueruli would need to be in the vicinity of the pipe entrances for entrainment to account for their high occurrence within the power station. Assuming pueruli were available from 1 h after sunset to 1 h before sunrise, and all turbines on load, then average densities at the power station during the peak catching month (July 1982) reached 6.4×10^{-5} pueruli per m^3 sea water. Similar puerulus densities inshore (about $1.0–4.7 \times 10^{-5}$ specimens per m^3 sea water) were estimated for Gisborne during the months of peak local settlement (author's unpubl. data from fine-meshed mid-water trawling). Settlement of pueruli on collectors near Gisborne is relatively high (Booth & Tarring 1986), large numbers of undersized rock lobsters occur nearby (e.g., see McKoy & Esterman 1981), and there is a very substantial fishery (Sanders 1985). One explanation for these inconsistencies is that the power station attracts pueruli. Phillips & Macmillan (1987) found receptor organs on the antennae of *P. cygnus* pueruli which may allow the animal to orientate to vibrational clues associated with the coast. The power station produces noise during the combustion of fuel and associated processes, which is conducted to the nearby sea, and to which the *J. edwardsii* pueruli may be responding.

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